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Visual Search and Target Cueing: A Comparison of Head-Mounted Versus Hand-Held Displays on the Allocation of Visual Attention

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ABSTRACT

We conducted a study to examine the effects of target cueing and conformality with a hand-held or head-mounted display to determine their effects on visual search tasks requiring focused and divided attention. Eleven military subjects were asked to detect, identify, and give azimuth information for targets hidden in terrain presented in a simulated far domain environment while performing a monitoring task in the near domain using either a helmet-mounted display or hand-held display. The results showed that the presence of cueing aided the target detection task for expected targets but drew attention away from the presence of unexpected targets in the environment representing a form of cognitive tunneling. This effect was mediated by the display platform used, such that cognitive tunneling was reduced when subjects were using the hand-held display. Additionally, the results showed that the presence of cueing hindered performance on the secondary task.

1. INTRODUCTION

The ground soldier of the future will be assisted by electronic information delivered to the field (National Research Council, 1997). An important issue concerns the display platform upon which or within which, this information will be presented, in a format that it can be most useful, and least disruptive of other tasks. At least two solutions are available. One is to capitalize upon existing helmet-mounted display (HMD) technology (e.g., for providing night vision information), in order to add to the HMD additional electronic information, regarding mission requirements, terrain, or the evolving aspects of the battle. The other is to provide similar information on an electronic hand-held display.

The contrast between these two display platforms, parallels a contrast that has been examined more extensively in the aircraft and to a lesser extent in ground vehicles, between presenting information on a head up display (HUD), overlapping the forward field of view, versus the head down instrument panel (Weintraub & Ensing, 1992; Wickens, 1997). Experimental evaluations of this comparison in the HUD studies has revealed a tradeoff between two critical attentional variables: the costs to focused attention, related to the clutter of overlapping imagery, when information is presented head up so that it is superimposed on the outside scene creating often a cluttered view, and the costs to divided attention, or information access, when information is presented head down, and the operator (pilot or driver) must now scan between the display and the outside world.

Research that has compared these two platforms (Wickens & Long, 1995; Martin-Emerson & Wickens, 1997; May-Ververs & Wickens, 1998; Fadden & Wickens, 1997), has revealed that the costs of scanning, associated with head down presentation, generally outweigh the costs of clutter, associated with head up presentation, thereby generally favoring the latter. However such research also indicates that the clutter costs become greater and more disruptive, as more information is added to the HUD (May-Ververs & Wickens, 1998), and that these costs are also more strongly realized in detecting events in the world if those events are unexpected, and not salient (Wickens & Long, 1995; Wickens, 1997).

Research on HUDs has also revealed that the clutter costs can be moderated, or even eliminated, through the use of conformal imagery. That is, information which has direct spatially

defined referents in the world beyond. Such imagery has sometimes been characterized to create an augmented reality (Drasac & Milgram, 1996), in the sense that the far domain imagery (reality) that is directly viewed, is augmented by computer imagery that indicates or highlights particular locations, objects, or dimensions within that reality.

Two different forms of such augmented reality or conformal imagery may be provided: that which conforms to relatively enduring characteristics of the far domain environment, such as a horizon line, a compass scale, or the contours of the terrain; and that which conforms to the location (or identity) of relatively transient entities within the far domain – for example a desired ground track or, in the experiment we report here, cueing the estimated location of particular enemy targets. Of course such cueing can readily be presented head down as well as head up. However in the head down position, it appears less "natural" and direct, and requires a greater degree of cognitive transformation, to use the cue to identify a direct position in space. Indeed in the HUD research, we have found that the benefits of conformal cueing (locating the runway) are considerably enhanced when presented in a head up, rather than at a head down location (Wickens & Long, 1995; Fadden & Wickens, 1997).

The effectiveness of conformal and non conformal cueing in an HMD was examined by Yeh, Wickens, and Seagull (1998). In their experiment, soldiers sat in a virtual environment (CAVE), and were asked to scan for, and detect a series of targets (soldiers, tanks, mines and nuclear devices) that could appear, partially masked, against the mountainous terrain surrounding them. Concurrently they performed a secondary task. The investigators found that when the imagery was conformal or "world referenced", there was an overall benefit to target detection. There was also an overall benefit of target cueing (independently of the degree of conformality), such that a reticle pointing to the location of targets facilitated their detection. However, a somewhat disconcerting result was that cueing in particular imposed a COST on the detection of simultaneously viewable uncued targets of higher priority, the nuclear devices. Yeh, Wickens, and Seagull attributed this cost to a sort of attentional tunneling, resulting from the very compelling nature of the cue, directing the soldier's attention to the cued location, but in the process, disrupting the need to maintain a broader scan, to detect the infrequent, but **HIGHLY IMPORTANT** target. The investigators also found that the cost of cueing was slightly modulated by the nature of the display, enhanced in the screen-referenced, relative to the world-referenced display.

A similar finding, in a different environment, was observed by Bossi, Ward, Parkes, and Howarth (1997). In a vehicle driving simulator, they found that highlighting the center of the highway, via an enhanced vision system, facilitated the highlighted task (road following), but at the expense of detection of more peripheral targets.

Yeh, Wickens, and Seagull did not look at the hand-held display (i.e., one without overlapping imagery) in their experiment, and thus their findings cannot as address the issue of the clutter-scan (focused-divided attention) tradeoff that underlies much of the HUD research. Nor can their results directly address how such a tradeoff may be moderated by features of the conformal (world referenced) imagery, in a way that might guide designers to present information that is most usable, and least disruptive of the soldier's need to monitor the environment beyond.

This then is the specific objective of the current experiment, in which participants perform the same combination of a target detection and identification task and a secondary monitoring task, that was used by Yeh, Wickens, and Seagull. In one condition they do so using a helmet mounted display with conformal imagery (i.e., augmented reality); in a second condition, the same information is presented on a hand-held electronic map. Either display location is sometimes augmented by target cueing, and both cued and uncued targets may sometimes be accompanied by a higher priority, but unexpected (i.e., low frequency) nuclear weapon. Our interests are in the extent to which (a) clutter and scanning trade-off with each other, (b) the expected benefits of target cueing are enhanced when the cues are rendered in the HMD, rather than on the hand-held display, and (c) the extent to which benefits of cueing may be offset by costs of detecting uncued, but high priority targets, and that these costs themselves may be modulated by the platform of the display.

2. METHOD

2.1. Subjects

Eleven Army personnel (three officers and eight Reserve Officers Training Corps cadets) at the University of participated in the experiment.

2.2. Task Overview

The task performed by subjects consisted of three stages: (a) target detection, (b) target identification, and (c) target heading. The target *detection* task (the primary task) required subjects to scan the display looking for any one of four target objects: three of the targets were presented on a total of 90% of the trials (30% each) and were therefore expected; the fourth was presented only 10% of the time and was unexpected. Subjects were not told which target to search for. While searching for the target, subjects were asked to perform a secondary monitoring task, displayed on the simulated HMD, which stopped once the target was found.

Cueing of the target's location was presented for half the expected targets to aid the detection task; the unexpected target was never cued. Targets were presented serially; only one target was displayed at any time, except in the case of the unexpected target, which was always presented in conjunction with an expected target. However, only one object was detected per trial. Subjects were instructed that detecting the unexpected target – a nuclear weapon – took precedence over standard target detection.

Once the target was found, the subject was required to *identify* the target as either friend or foe and give the target's *heading*, the current compass direction of the target with respect to his current location.

2.3. Apparatus

The terrain was displayed on the walls of the Cave Automatic Virtual Environment (CAVE), a 10x10x9-foot room sized video environment. The subject was seated in the center of the CAVE. A DataVisor VGA HMD was used for the HMD condition. Although symbology was displayed monocularly to the subjects' right eye, subjects' field of view (i.e., the amount of information available to both eyes) was constrained to 30°. The symbology was presented in a 25° field of view.

In the hand-held condition, subjects viewed the image presented on a hand-held display with a 2.5" screen. They were required to wear head-tracked shutter glasses, which were not turned on, but reduced the saliency of the far domain targets to equal that of the view through the HMD. The symbology on the hand-held display was visible to both eyes.

2.4. Displays/Tasks

The displays were created from static two-dimensional renderings of three-dimensional images depicting hilly terrain. The terrain was developed using geographical data of Austin, TX, Detroit, MI, and Jordan Valley, UT, downloaded from the U.S. Geological Survey web site. The target stimuli, shown in Figure 6.4.1, were placed in the terrain.

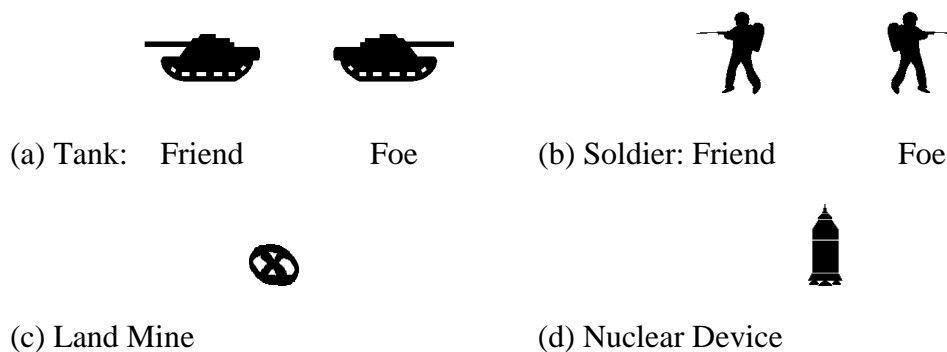


Figure 2.4.1. Stimuli: (a) Tanks (cued), (b) Soldiers (uncued), (c) Land Mine, (d) Nuclear Device.

The tanks, soldiers, and nuclear devices were camouflaged, i.e., colored in shades of brown, green, and black; land mines were presented in black. Since the shading of the terrain varied, the intensity of the targets was adjusted adaptively at each location so that the contrast ratios between the target and the terrain were similar for all targets. The greater salience of the nuclear device was insured by presenting them at a higher contrast ratio with the background than the other three targets. The location of tanks and 50% of the land mines were cued with an arrow pointing in the direction of the target based on the subject's current head position. All soldiers and 50% of the land mines were uncued. The presence of cueing was randomized (i.e., unpredictable) over trials.

Friend-or-foe identification was based on the direction in which the target was pointing. Friendly targets pointed towards the left and enemy targets pointed towards the right. No identification was required if the target was a land mine or nuclear device.

Head Up Display

An example of the head-up (HMD) display is presented in Figure 2.4.2, which depicts the field of view of the symbology, the horizon line, the cueing arrow, and the box containing the secondary task.

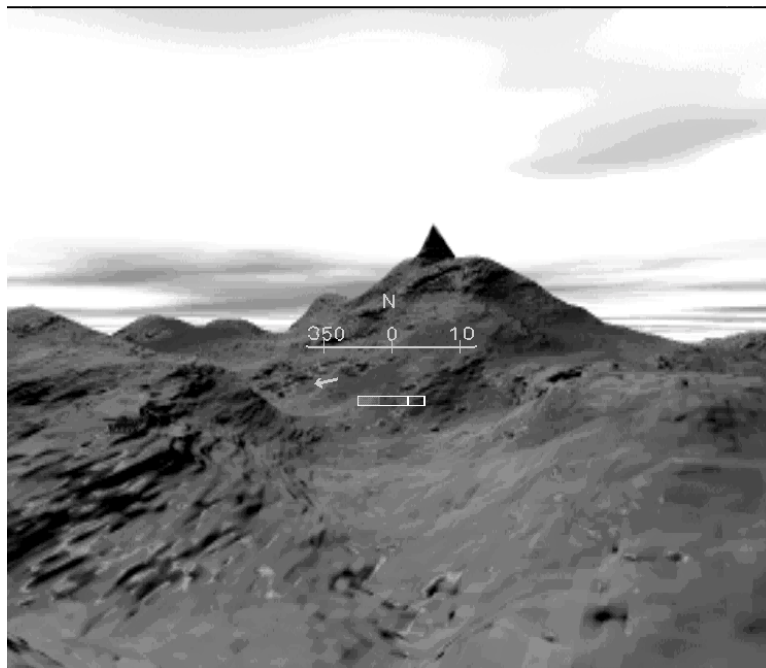


Figure 2.4.2. HMD display.

In Figure 2.4.2, the pictures show symbology presented in the HMD superimposed onto the terrain presented on a CAVE wall. Symbology was presented in green. The visual region of HMD-depicted information was only 25° laterally x 30° vertically. The field of view presented to the subjects was slightly less than the 40° available in night vision devices and significantly smaller than the 60° required by the Army for the Land Warrior System.

Heading was presented conformally (i.e., world-referenced) with respect to the horizon line. The four cardinal directions were marked on each heading tape. Note that the heading information in Figure 2.4.2 was superimposed on the true horizon line, and as a result, the location of the heading tape on the HMD changed as the subject moved his head vertically in order to examine the environment.

On cued trials, a cue was presented to signal the current lateral and vertical location of a target with respect to the subject's head orientation. For example, if the target was presented to the right of the subject, then a right pointing arrow appeared on the HMD as shown in Figure 2.4.2, indicating the presence and general direction of a target. If the target was above and to the right of the subject – e.g., located on top of a mountain, then an arrow pointing towards the upper right corner of the HMD appeared. The arrow would change its orientation accordingly as the subjects moved his head toward the target. Note that targets appearing directly in front of the subject within the forward field of view were not cued by this symbology but rather designated by a target lock-on indicator, or reticle, which will be discussed later.

Cueing information was presented in a partially head-referenced format. A cueing arrow positioned on the perimeter of the screen display, pointed directly toward the 3D location of a target. In this example, the arrow would indicate that the target was to the right and above. The cueing arrow could be positioned at the edges of the perimeter of a circle whose diameter subtends 21° of visual angle.

Once the target was in the subject's field of view, i.e., visible through the HMD, a target lock-on reticle appeared on the display conformally as shown in Figure 2.4.3.



Figure 2.4.3. Target lock-on. Note that the tank is in the far domain and is being viewed through the HMD.

As Figure 2.4.3 shows, the lock-on reticle was displayed over the actual object. Due to variability in the head tracker attached to the HMD, the cueing was somewhat imprecise; thus, the lock-on reticle could be slightly off target at approximately 0°-3° in the x-, y-, or z-directions. Our previous research (Yeh, Wickens, & Seagull, 1998) had revealed that this imprecision created no difficulties in target detection since, in any case, the target was within foveal vision when the lock-on reticle was fixated. The lock on reticle was *not* used to signal the presence of any uncued targets which might appear in the subject's forward field of view.

Hand-held display

An example of the hand-held display is presented in Figure 2.4.4.

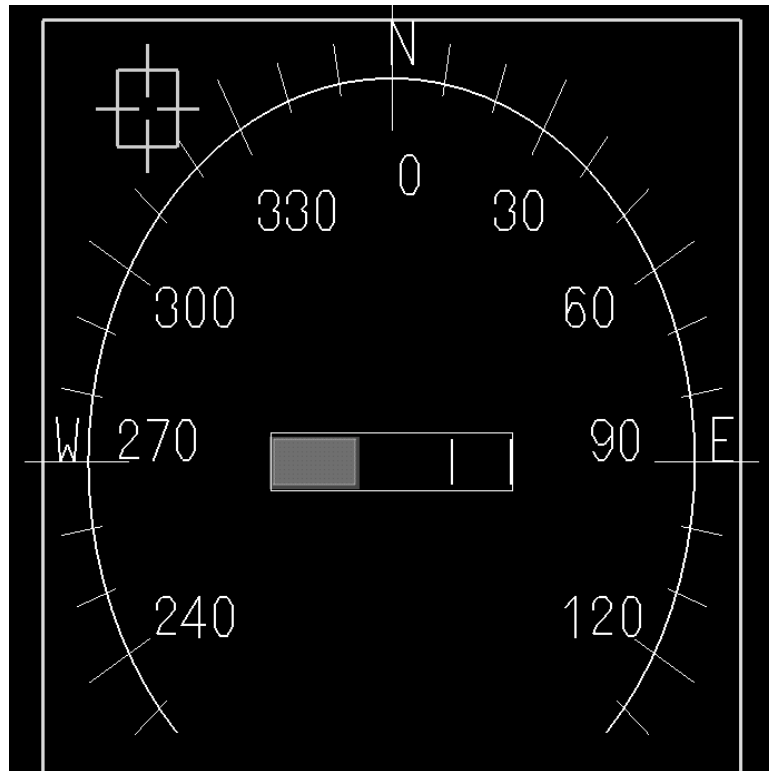


Figure 2.4.4. Hand-held display.

As Figure 2.4.4 shows, the hand-held display provided subjects with a simple diagram of the world, heading information, cueing information, and the secondary task. The information on the hand-held was presented non-conformally, i.e., if the subject would move the display in the environment, the positioning of the symbology (heading and cueing data) did not change. Representation of the walls of the CAVE (the lines at the edge of the display) were drawn in blue, and the heading information was presented in white against a black background.

On cued trials, a cue was presented to signal the current lateral location of a target. This cue was independent of the subject's head or hand orientation; in other words, the presentation of the cue did not change when the target was within the subject's field of view. Thus, the arrow, which in the head-up condition cued subjects to the target's location, was not included in this display.

2.5. Secondary Task

Subjects were given a secondary monitoring task, to perform continuously throughout the experiment. In the HMD condition, the task was presented monocularly to the right eye; in the hand-held condition, the task was presented to both eyes. Note that the task was a two-dimensional task; thus, viewing the secondary task with two eyes versus one would not result in different perceptions of the same image.

Subjects were told that enemy troops were tracking their location by using radio frequency as input. Thus, as the subjects searched for targets, they were also required to jam the enemy's radar frequency so that they remained undetected. To do this, subjects needed to monitor a horizontal bar, presented at the lower left edge of the HMD (as shown in Figure 2.4.1) and in the center of the hand-held display (as shown in Figure 2.4.4.). The solid bar gradually grew longer horizontally, filling in the rectangle from left to right. When it passed the first marker, subjects had 5 seconds to jam the enemy's frequency by responding with a button press. Responding before the solid bar passed the first marker had no effect. The solid bar increased at a variable rate created as the sum of four sine functions. The bar reached the first marker between three and five seconds from the start of the secondary task. Once subjects responded to the task, the bar would reset. The task continued until the target was detected.

2.6. Experiment Design

The experiment was a mixed design as shown in Table 2.6.1.

Table 2.6.1. Experimental design.

		Within Subjects					
		Display					
		Head-Up		Head-Down			
Between Subjects	Reward	<div><div>TARGET TYPE</div><div><div>CUED</div><div>UNCUED</div></div><div><div>Tank Mine</div><div>Mine Soldier</div><div>Nuclear Device</div></div><div><div>← Expected →</div><div>Unexpected</div></div></div>				TARGET TYPE	
	No Reward	TARGET TYPE		TARGET TYPE			

As Table 2.6.1 shows, the presentation of display [head-up (HMD) versus head-down (hand-held)] and the manipulation of target type (cued versus uncued targets, high versus low expectancy) were examined within subjects. The manipulation of reward was analyzed between subjects. The first three subjects in the experiment reported that the information presented on the hand-held did not add much to their task, and were thus scanning the environment naturally; as a consequence, the rate of misses for the secondary task was at 26% for the hand-held display. Thus, we added an incentive; subjects were ranked based on their performance on the secondary task and could earn \$40, \$20, or \$10 for first, second, or third place in terms of task performance. To prevent subjects from responding to the secondary task randomly (e.g., selecting the button every 3 seconds or so), the remaining subjects were told that they would be penalized if they responded either too early or too late. The secondary task was present on all trials.

Six different terrain views, created from taking static “pictures” at different locations of topographical regions, were used in the experiment. For each viewing condition, subjects were presented with one practice block, consisting of ten search trials, and ten experimental blocks, each containing a set of twenty search trials. The presentation of target stimuli (i.e., tanks, land mines, and soldiers) was serial – that is, only one target was presented per trial and subjects searched the three walls of the CAVE until it was located. The exception was the presentation of the nuclear device, which would appear concurrently with one of the other targets.

In the practice block, subjects viewed ten targets, presented serially. The targets consisted of three tanks, three soldiers, and three land mines, each, and one nuclear device. Tanks, soldiers, and land mines appeared once on each of the three walls. Each experimental block consisted of a total of 20 targets; 6 each of tanks, soldiers, and land mines and 2 nuclear devices. Half the tanks and half the soldiers were friendly – the other half were enemy. On a random half the trials, cueing was present. This was the case for all tanks and half of the mines. Thus, the presence of the cueing symbol provided subjects with a partial reduction of uncertainty of target type. Each object appeared twice on each wall, except for the nuclear device which appeared once on the left wall and once on the right wall. Targets were presented serially, except for the nuclear device, which was presented in conjunction with either a cued target (tank) or an uncued target (soldier). As it was an “unexpected” target, the nuclear device was presented within 15° of either the tank or the soldier with which it was presented to maximize the likelihood that the unexpected target would appear in the subject’s field of view as the subject searched for the target (e.g., if the target was a tank located in the center of the left wall, the nuclear device would have been positioned to the right of the tank so that the subject’s field of view would pass over the unexpected target as he moved his head from the center wall to the left wall). Subjects were told that a nuclear device could be present on any of the trials.

2.7 Procedure

The experiment took approximately 2.5 hours during which subjects were given the instructions for the experiment and then performed the experiment. Subjects were instructed to pretend that they were scouts, sent to search for enemies and allies in unfamiliar territory. Their primary task was to find the targets, identify them as friend or foe, if relevant, and send information back to their troop regarding the objects’ position. Their secondary task, was to monitor a radio frequency display, which provided data as to how close the enemy was in tracking their position.

Subjects interacted with the display using a wand and shutter glasses. A diagram of the wand is presented in Figure 2.7.1.

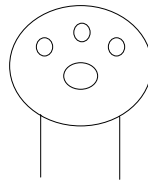


Figure 2.7.1. The wand.

The wand has three buttons and a pressure-sensitive joystick. Only the buttons were used during the experiment to make responses. The joystick was not used at all.

While searching for the target, subjects responded to the secondary task by pressing the right wand button. To indicate that a target was detected, subjects pressed the left button on the wand. For, the target identification task, subjects pressed the left button on the wand again if the target was foe, the center button if the target was friendly, or the right button in the case of a nuclear device. Subjects did not need to identify whether the target was a tank, soldier, or land mine. Note that the button pressed for friend and foe identifications corresponded to the direction the object was pointing, e.g., subjects pressed the left button if the tank or soldier was pointing left. Once the target was detected (land mine) or identified (tank, soldier, or nuclear device), subjects verbally reported its location by stating the target's bearing.

Once the target was detected and reported, the display was darkened. When the subject's head was centered, a subsequent trial, containing a new target, was initiated.

After each twenty trial block, subjects were asked to "describe" the location of the targets they had encountered within the environment to their commanding officer by selecting one of four pictures of the environment, one of which depicted the objects in the same location as in the environment they had seen. Of the three incorrect pictures, one showed the tanks placed in different positions, another presented the soldiers in different locations, and the third depicted the land mines in incorrect sites. Not all the targets were presented. That is, targets presented on nuclear device trials were omitted from the pictures since it was not known which target subjects would detect in the nuclear device trials – i.e., would subjects see the missile or would the tank or soldier appearing with the missile capture their attention instead.

The order in which subjects viewed the symbology (head-up versus head-down) was counterbalanced.

2.8. Performance Measures

The dependent variables collected from the primary target search task were response time and accuracy for target detection, target identification, and target heading. In order to determine whether the symbology influenced the amount of scanning in the environment, data describing the amount of head movement along the x-, y-, and z- axes were collected. Additionally, data

concerning the number of times and the amount of time the target was in the view (within 60°, 21°, and 15°) were collected. Note that the center points for the aforementioned view angles are at the center of the HMD and shutter glasses, rather than the center of the eyes. Thus, it was possible for a target to pass through the area in the center 15° of the shutter glasses and go unnoticed by the subject, if his eyes were rotated away from the forward axis of the head.

The measures collected from the secondary task were response time and accuracy. Since each subject took a different amount of time in detecting the targets, the number of frequency jamming events varied. Thus, accuracy for the task was calculated as a proportion of the number of hits to the number of total frequency jamming tasks viewed.

Finally, measures for the global positioning task were response time, accuracy, and subjects' confidence ratings of their responses.

3. RESULTS

The data were examined in order to determine the effects of expectancy and cueing on target detection and how well attention could be allocated between the near and far domains. Differences in display (HMD vs. hand-held) were hypothesized to mediate these effects. Since it was possible for subjects to mistake a terrain feature for an object, trials with heading errors of azimuth estimation greater than $\pm 20^\circ$ were assumed to result from this confusion, were scored as incorrect and replaced with the subject's mean response time for like targets in that particular block (i.e., involving the same terrain) displayed on the same wall. This was approximately 5% of the trials. Additionally, outliers which were greater than ± 3 standard deviations from the mean were replaced in the same way; this was approximately 1% of the trials.

The total data set represented ten dependent variables, consisting of response time and accuracy measures for the primary tasks of target detection, identification, and location, the frequency jamming secondary task, and the global positioning recognition task. These dependent variables were influenced by multiple factors (independent variables):

- Target type, which could be subdivided into comparisons of expected vs. unexpected targets and cued vs. uncued targets
- Display: HMD vs. hand-held
- Wall: left, center, or right

Because we do not hypothesize that all dependent variables would plausibly be influenced by all independent variables (or if they were, such influences would not be of theoretical or practical interest), we do not report full ANOVAs on all dependent variables. Instead, we parse the presentation of results into six categories:

1. Effects of target type (expectancy and cueing) and display on the primary and secondary tasks (3.1-3.5)
2. Effects of wall (3.6)

Within each of these sections, we present and describe only those effects (and their interactions) that are most relevant to understanding the influence of display augmentations on target detection.

3.1. Expectancy

The effects of a subject's expectation of a target was examined by comparing detection performance for tanks and soldiers – both highly expected targets – with detection of nuclear devices – infrequent, low expectation targets. Subjects were instructed that the latter were of higher priority. The nuclear device trials were separated into two classes based on whether the nuclear device was presented concurrently with a tank or with a soldier. Although mines were also expected targets, the mine trial data were not used for this analysis since mines were cued on half the trials, thus confounding the measure of expectation. Note also that the presentation of the unexpected targets (nuclear devices) never occurred concurrently with a mine. No comparisons were made between the two expected targets (tanks and soldiers) as variables affecting performance could not be attributed solely to cueing, i.e., tanks were cued and soldiers were not, but there were also possible confounding differences attributable to in the physical appearance of the stimuli. The direct effects of cueing will be examined in the analysis of mine detection (Section 3.2).

A 2 (display: HMD vs. hand-held) x 4 (target type: expected and cued (tank), expected and uncued (soldier), unexpected with cued (nuclear device presented with a tank), unexpected with uncued (nuclear device presented with a soldier)) within subjects ANOVA was conducted on the accuracy and response times for the target detection task. Figure 3.1.1 presents the effects of display and target type on response time (left) and accuracy (right). The bars in the figures show ± 1 standard errors from the mean.

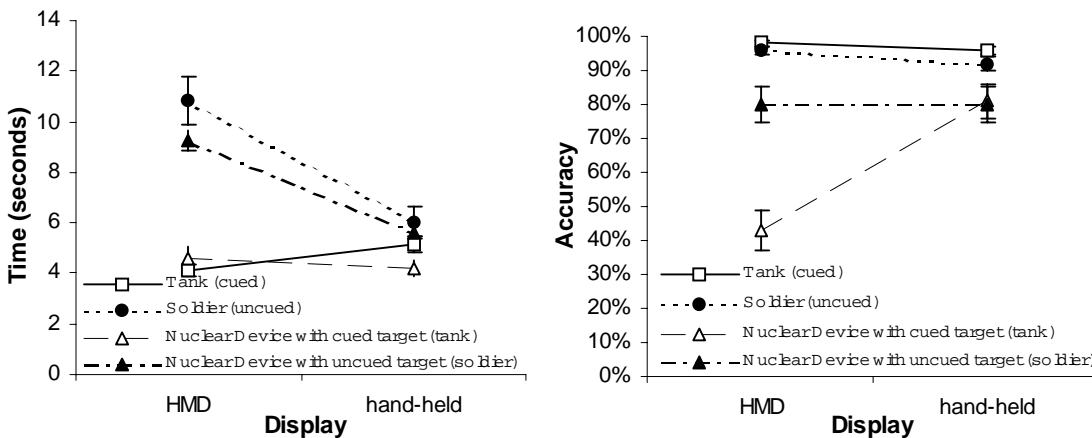


Figure 3.1.1. Response time and accuracy for expected and unexpected targets.

In the graph, the filled symbols are responses when the uncued target (soldier) was present, the open symbols represent responses when the cued target (tank) was present, and the triangles represent the data points for the nuclear devices. The main effect of display, $F(1,18) = 10.21$, $p = .005$, suggested an advantage for the hand-held display, and the main effect of target type, $F(3,54) = 32.67$, $p = .0001$, suggested that the most rapid responses occurred on cued trials. The significant interaction between display and target type, $F(2,54) = 16.26$, $p = .0001$ suggests that the cueing effect was enhanced when using the HMD, and that the HMD cost was only observed on cued (i.e., tank) trials. More detailed comparisons within the target types revealed no difference between the uncued nuclear weapons and the targets with which they were paired [nuclear device vs. tank, $F(1,18) = .01$, $p = .93$; nuclear device vs. soldier, $F(1,18) = .76$, $p = .40$], although a slight benefit was present for detecting the nuclear weapons over the tanks and soldiers when subjects used the hand held display, $F(1,18) = 18.68$, $p = .0004$, and $F(1,18) = 24.09$, $p = .0001$.

As shown in Figure 3.1.1(b), the latency advantage for the nuclear weapons detection was purchased at a cost for accuracy. The main effect of target type, $F(3,54) = 13.33$, $p = .0001$, reflected this cost (a 25% reduction in hit rate for the nuclear weapons compared to near perfect detection for the more expected soldiers and tanks). More specifically, the target x display interaction, $F(3,54) = 7.32$, $p = .003$, suggested that this cost was amplified only when the nuclear device was paired with a cued tank when using the HMD.

3.2 Benefits of Cueing

In order to determine the effect of cueing, unconfounded by stimulus type, a comparison of the detection of cued versus uncued land mines was conducted. The data were analyzed using a 2 (display) x 2 (cueing: cued vs. uncued) x 3 (wall: left, center, and right) within subjects ANOVA. Figure 3.2.1 shows the results for the target detection task.

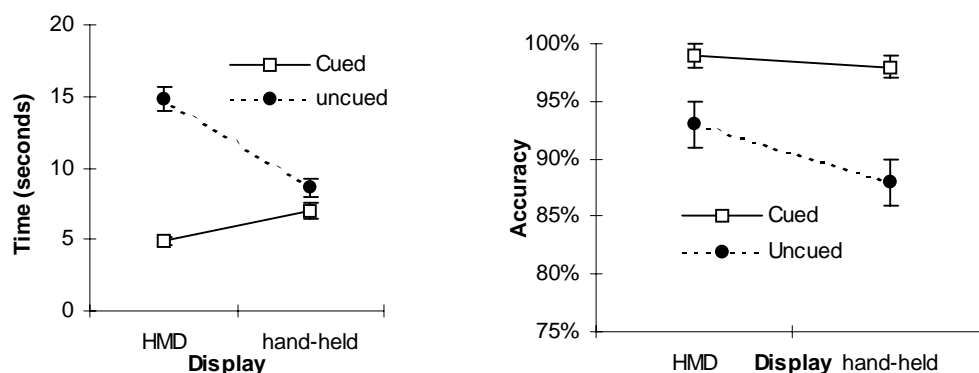


Figure 3.2.1. Effects of cueing: land mine detection.

Data regarding mine detection showed a large response time benefit for target cueing, $F(1,18) = 42.05$, $p = .0001$, replicating the cueing response time advantage for tanks seen in Figure 3.1.1. There was a marginal effect of display, $F(1,18) = 3.75$, $p = .07$, and a significant interaction between target cueing and display, $F(1,18) = 28.27$, $p = .0001$, indicating that the cueing benefit was enhanced in the HMD, relative to the hand-held display, and as shown in Figure 3.1.1, the HMD costs were observed for uncued, but not cued targets.

Analysis conducted on the accuracy data also revealed a benefit for cueing, $F(1,18) = 13.12$, $p = .002$. There were no differences due to display, $F(1,18) = 2.17$, $p = .15$, nor was the interaction between cueing and display significant, $F(1,18) = .18$, $p = .68$.

3.3 Divided Attention: Results of Secondary Task Performance

In order to determine how well subjects were able to divide their attention between information presented in the display and information in the far domain, ANOVAs were conducted on the response time and accuracy data for the secondary task. A 2 (display) x 2 (cueing) x 2 (reward) ANOVA was conducted on the data for secondary task performance. The latency and accuracy with which subjects responded to the secondary task are presented in Figure 3.3.1.

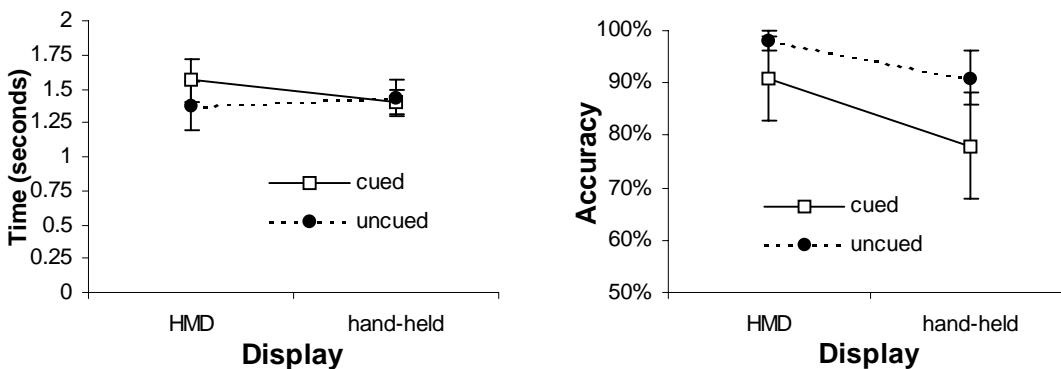


Figure 3.3.1. Response time and accuracy for the secondary task.

The response time data showed no effect of display, $F(1,18) = .17$, $p = .68$, cueing, $F(1,18) = .21$, $p = .65$, reward, $F(1,18) = 1.62$, $p = .22$, nor an interaction between cueing and display, $F(1,18) = 1.91$, $p = .18$.

The accuracy data revealed no effect for display, $F(1,19) = 1.42$, $p = .25$, but a marginal effect for target cueing, suggesting that subjects were able to focus their attention more effectively on the secondary task when there was no target cueing on the display, $F(1,19) = 3.42$, $p = .08$. The interaction between display and cueing was not significant, $F(1,19) = .34$, $p = .56$.

The results for the reward manipulation are presented in Figure 3.3.2.

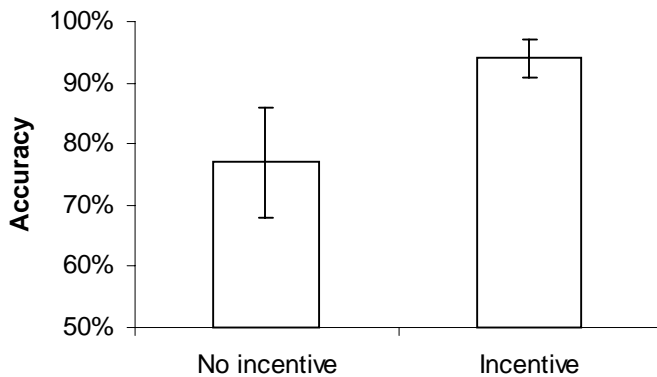


Figure 3.3.2. Accuracy: reward versus no reward.

The results showed that performance on the secondary task marginally improved when subjects were given an incentive, $F(1,19) = 3.58$, $p = .08$, but the data from both groups showed the same trend, as reported above in the context of Figure 3.1.1.

3.4 Display Effects for Target Identification and Heading Tasks

The results presented so far have described the data analysis of the effects of cueing and expectancy on allocating attention between the near and far domains to detect secondary task events and targets respectively. Subjects were also asked to perform two far domain tasks in addition to target detection – target identification and target heading estimation – in order to determine whether the use of conformal or non-conformal imagery could facilitate performance once the target had been detected. These were essentially single task responses, since the secondary task was inactive during this phase. Response time for the target identification task was measured by the time delay between detection and identification. As noted, identification was not required for the mines or nuclear devices, since these were always assumed to be hostile. A 2 (display) x 2 (target type: tank, soldier) within subjects ANOVA was conducted for the target identification task. Figure 3.4.1 shows the results for the identification task for the tanks and soldiers.

As Figure 3.4.1 shows, there was no effect of display for either response time [$F(1,18) = .45$, $p = .50$] or accuracy [$F(1,18) = .01$, $p = .94$]. However, a marginally significant interaction between target type and display [$F(1,18) = 4.20$, $p = .06$] was present for the accuracy data, such that accuracy in identifying the tank was less accurate when information was presented on the HMD rather than the hand-held display, but that the accuracy in identifying the soldier was influenced little by display. We may attribute the accuracy cost to the tank to the cueing reticle which sometimes cluttered the view of the tank (but was never present for the uncued soldier).

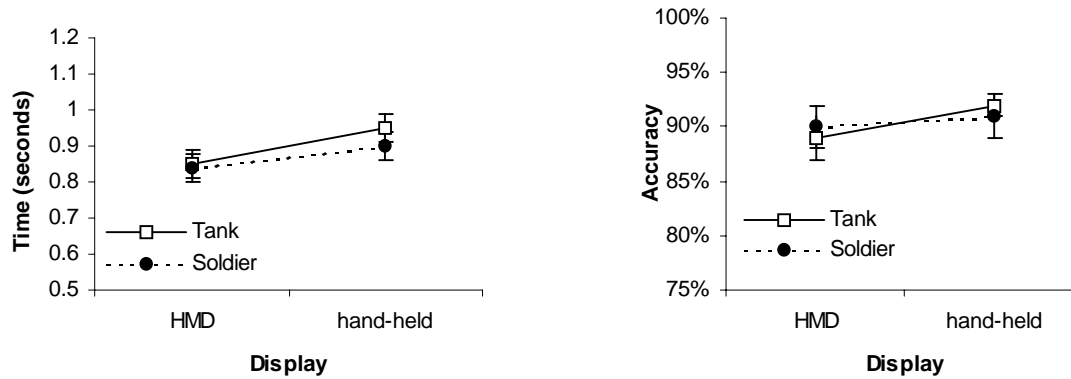


Figure 3.4.1. Response time and accuracy for the identification task.

Data for the target heading task were analyzed using a 2 (display) x 4 (target type: tank, soldier, mine, and nuclear device) within subjects ANOVA. When determining the accuracy for the target heading task, errors in heading greater than $\pm 10^\circ$ were considered incorrect. The results are presented in Figure 3.4.2.

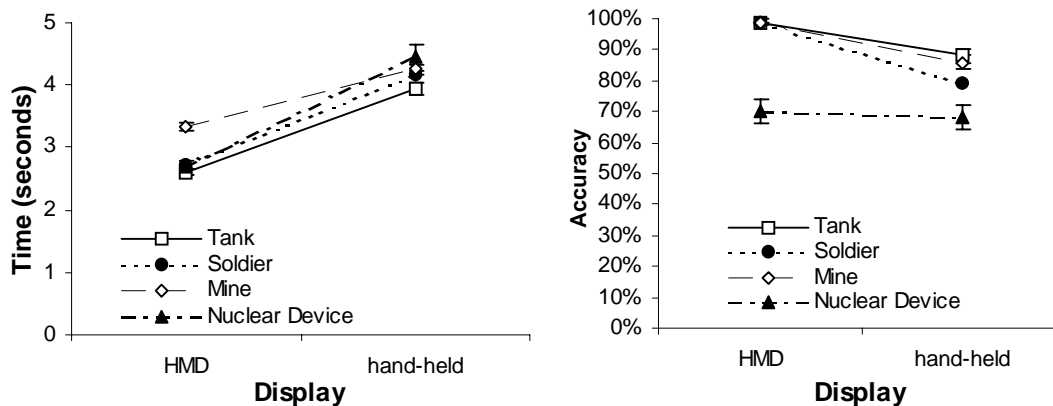


Figure 3.4.2. Response time and accuracy for the target heading task.

Heading information was given faster by subjects using the HMD rather than the hand-held display, $F(1,16) = 12.09$, $p = .003$. A main effect of target type was present suggesting slower responses for the mines, $F(3,48) = 8.50$, $p = .001$. However, an interaction between target type and display [$F(3,48) = 3.24$, $p = .05$] suggested that this slowing was only observed with the HMD.

The influence of display on target heading accuracy is also depicted in Figure 3.4.2. The analysis showed a main effect of display, $F(1,16) = 33.53$, $p = .0001$. A significant interaction between target type and display was present, $F(3,48) = 4.29$, $p = .05$, such that heading accuracy

for the three expected targets (tanks, soldiers, and land mines) was higher with the HMD than with the hand-held display, but the opposite was true for the unexpected target (nuclear device).

3.5 Global Positioning Task

A 2 (display) x 5 (terrain) ANOVA was conducted on the accuracy for the global positioning task, as presented in Figure 3.5.1.

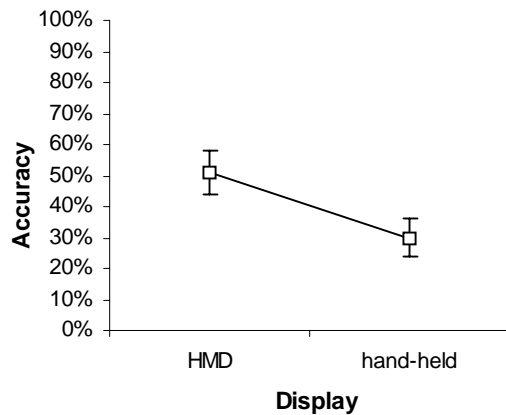


Figure 3.5.1. Accuracy for the global positioning task.

The analysis showed an effect of display, $F(1,98) = 5.00$, $p = .03$, such that recognition accuracy was greater when subjects viewed the terrain with the HMD than the hand-held display.

Subjects were also asked to give a confidence rating (1 = not confident, 5 = confident) as to the certainty of their answer. The accuracy data were then converted into performance scores based on subject's confidence ratings according to the scale presented in Table 3.5.1. Scores were decreased with *lower* confidence when the accuracy was correct, and decreased with *higher* confidence when accuracy was incorrect.

Table 3.5.1. Confidence score based on response accuracy.

Correct		Incorrect	
Confidence	Score	Confidence	Score
5	10	1	5
4	9	2	4
3	8	3	3
2	7	4	2
1	6	5	1

Figure 3.5.2 shows the performance ratings for the global positioning task.

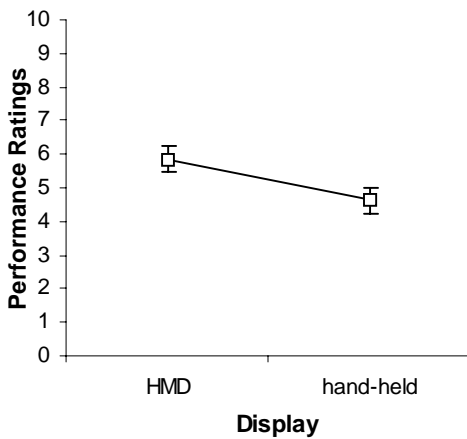


Figure 3.5.2. Performance ratings for the global positioning task.

The data showed an effect of display, $F(1,98) = 4.6$, $p = .03$; subjects were more accurate and more confident when they used the HMD rather than the hand-held.

3.6 Scanning Strategies

The data for detected expected targets were further examined in order to provide some insight into subject's scanning strategies. Analysis was conducted in order to determine whether the location – or wall – on which the target item was presented played a role in subjects' ability to detect the target. A 2 (display) x 4 (target type: tank, soldier, cued mines, and uncued mines) x 3 (wall) repeated measures ANOVA was conducted on the response times and accuracy for target detection. Figure 3.6.1 shows the results.

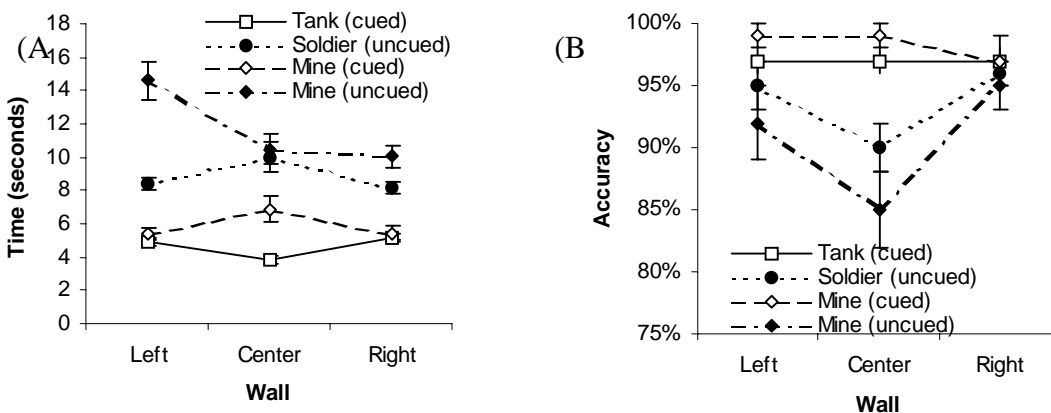


Figure 3.6.1. (a) Response time and (b) accuracy for target detection due to wall.

The results revealed no effect on response time due to the wall on which the target was presented, $F(2,36) = 1.90$, $p = .18$ but a significant wall x target type interaction, $F(6,108) = 5.95$, $p = .0001$. This interaction suggests a substantial left wall cost for the uncued mine; a cost not evident for the other three expected target types. Note that, as shown by the accuracy data, the uncued mines were the most difficult to detect.

The results for the accuracy data revealed a marginal effect due to wall, $F(2,36) = 2.71$, $p = .08$ such that target were detected more accurately on the right wall (97%) than on the center wall (93%), $F(1,18) = 13.12$, $p = .0001$. The interaction between wall and target type was not significant, $F(6,108) = 1.78$, $p = .15$.

Analysis on subjects' head motion along the x-, y-, and z- axes was also conducted using a 2 (display) x 4 (target type: tank, soldier, cued mines, and uncued mines) repeated measures ANOVA. The results are shown in Figure 3.6.2.

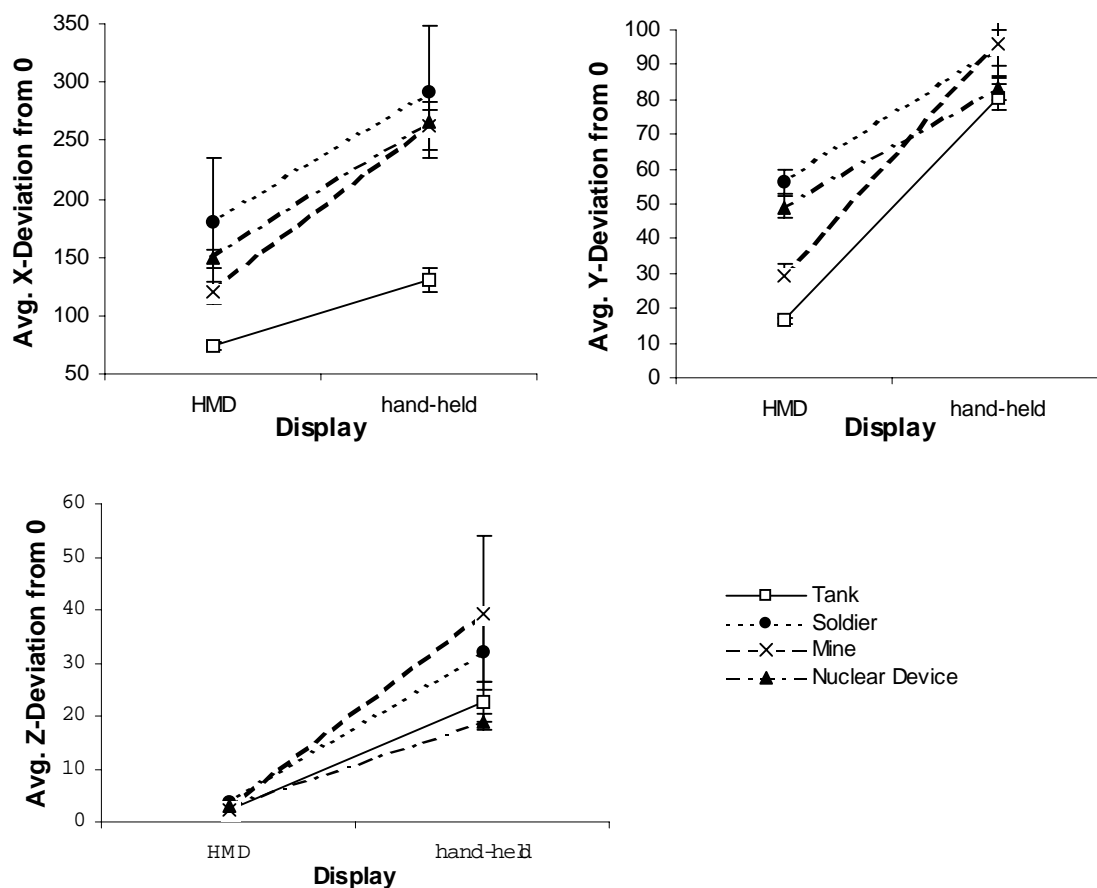


Figure 3.6.2. Head movement along the x-, y-, and z- axes.

The data revealed that wearing an HMD constrained head movements; subjects moved their head to scan the display significantly less in the x-, y-, and z- directions when wearing the HMD than when using the hand-held display [x-axis: $F(1,16) = 21.50$, $p = .0003$; y-axis: $F(1,16) = 17.20$, $p = .0008$; z-axis: $F(1,16) = 35.14$, $p = .0001$].

4. DISCUSSION

The current experiment was conducted to determine whether manipulations of helmet mounted and hand-held display design could aid tasks of focused attention in the near and far domains as well as divided attention between the two. The data suggest that subjects' expectancies of the targets and the presentation of cueing information aided visual search for expected targets in the simulated world, but that cueing sometimes captured attention in a way that resulted in a cost for the detection of unexpected and uncued targets in the far domain. The search task was a difficult one in the sense that subjects were searching for multiple targets whose identity was unknown. Their only clue available to reduce uncertainty was that if a cueing arrow was present at the start of a trial, then they needed to search for a tank, land mine, or nuclear device, and could exclude the soldier from the target search. If the cue was not present, targets in the far domain could be a soldier, land mine, or nuclear device. The greater the potential for multiple targets in the scene, the more mental templates the subject needed to activate in order to complete his task, and hence, the harder the task.

The results of the study show, not surprisingly, that target cueing aided the detection of cued targets, e.g., the always-cued tanks were better detected than the never-cued soldiers and the cued mines were better detected than the uncued mines. In making the former comparison, it is important to note that detection of soldiers and tanks were never compared in the uncued format, so that similarities or differences in the inherent detectability of the two shapes could not be determined, and were therefore confounded with cueing. However, a cost to target cueing was present, such that subjects were more likely to overlook a high priority but unexpected target (nuclear weapon), when it was paired with the lower priority cued target (tank) than with the lower priority uncued soldiers, as reflected in the accuracy data for expected versus unexpected targets shown in Figure 3.1.1. This effect replicated that observed by Yeh, Wickens, and Seagull (1998). However, Figure 3.1.1 also reveals that this cueing cost for detection of unexpected targets was only observed with the HMD. That is, this effect was mediated by display, such that relative to the HMD, the use of a hand-held display improved the accuracy of detecting a rare but important uncued target in the presence of a cued target.

We can try to interpret the HMD cost in the accuracy for detecting unexpected targets presented concurrently with a cued target in terms of the information access cost imposed by either clutter or scanning. One hypothesis is that the imagery on the HMD increased the clutter in the forward field of view and obscured the nuclear device even if it did not necessarily overlay it. If this were the case, then we would expect some HMD cost to nuclear device detection to be observed, whether cueing was present or not, relative to performance with the hand-held display; but this cost would be enhanced when cueing was present (adding to the clutter on the display). The accuracy data presented in Figure 3.1.1 only partially supports this hypothesis. While there was a significant cost for the HMD for detecting the unexpected target when additional information (cueing) was present in the forward field of view (tanks), there was no difference between the two displays in detection accuracy for the unexpected target in a "low" cluttered scene – i.e., when no cueing information was present (soldiers).

An alternative hypothesis, more consistent with the full data, is that the presentation of cueing information may have directed attention to a certain area of the visual scene, hence precluding scanning of the surrounding area. If this were the case, then the cost of detecting the

unexpected targets using the HMD relative to the head down display would be present only if cueing were present also. The accuracy data presented in Figure 3.1.1 support this hypothesis. That is, the augmented reality cueing in the HMD induces a sort of cognitive tunneling that is reduced when cueing is presented in its less “real” form on the hand-held display. Additionally, two other factors support this “tunneling” hypothesis of cueing effects: the limited field of view provided by the HMD and the weight of the HMD. When wearing the HMD, subjects could only see a maximum of 30° of the visual scene, but they could see up to 120° (i.e., the field of view of a person with normal vision) when using the hand-held display. Thus, information in the periphery, which provides information as to where the eyes should move next, was available when using the hand-held display but not when wearing the HMD. Consequently, subjects may have relied more on the cueing information provided by the HMD than that provided by the hand-held display to find the target, and were so focused on the cue that they missed the unexpected target even when it appeared within their visual field. On the other hand, when using the hand-held display, subjects were only directed to the general location of the target and thus were more likely to scan a wider area around the cued target and detect the unexpected target. Note that the difference in the field of view of the HMD can not otherwise account for the misses for detecting the nuclear device, because the nuclear device was presented within 15° of the target. Furthermore, if this were the case, we would have expected a reduction in nuclear device detection for both cued and uncued HMD trials. Figure 3.1.1 suggests that the cost was only present for cued trials.

The second factor for the HMD detection accuracy disadvantage is supported by the visual scanning data shown in Figure 3.6.2. The weight of the HMD reduced the amount of scanning of the environment and may have encouraged subjects to follow the cue to detect a target as quickly as possible (as supported by the detection time data in Figure 3.1.1), whether it was the high priority one or not.

Thus, the data suggests that the hand-held advantage in detecting the unexpected objects may be due to a cost in directing attention to different areas of the visual scene, i.e., a failure to scan. This is not a cost that has been extensively addressed by other HMD studies, although Seagull and Gopher (1997) did observe the inhibiting effects on scanning and attention allocation imposed by HMDs in a flight simulation. The results for unexpected event detection replicate the findings of Yeh, Wickens, and Seagull (1998), which showed that the unexpected target was detected more often when presented in conjunction with an uncued target versus a cued target, and extend the findings as to how display manipulations can reduce cognitive tunneling. In this study, while the use of world-referenced imagery facilitated detection of unexpected events relative to the use of screen-referenced (or non-conformal) imagery, the current results show that using a hand-held display facilitates performance relative to a world-referenced HMD.

In general, targets were detected faster when subjects were using the hand-held display rather than the HMD, but this benefit was limited to those instances when the targets were uncued (Figure 3.2.1). That is, for cued targets (the land mines), there was little difference in detection times due to display. The disadvantage for the HMD may be a result of: (1) the additional clutter in the forward field of view (e.g., the secondary task and occasionally, the heading information) may have increased the difficulty in target detection (May-Ververs & Wickens, 1998; Teichner & Mocharnuk, 1979), or (2) the limited field of view provided by the

HMD, which has been shown to lead to poorer target detection performance (Hettinger, Nelson, & Haas, 1994).

If the first factor were responsible for the results, we might expect that the cost of clutter on the HMD to be enhanced by targets of low salience (e.g., the mines) and low expectancy (the nuclear devices) in relation to those of higher saliency and expectancy. This hypothesis is based on the findings regarding the problems of low salience of rare event detection with the superimposed imagery, characteristic of head-up displays (Martin-Emerson & Wickens, 1997; Wickens & Long, 1995).

If, on the other hand, the second factor – the limited field of view – were responsible, we would expect a *greater* HMD time cost for the detection of more salient (and therefore more available to peripheral vision) uncued soldiers than for the less salient uncued land mines, relative to the hand-held display. That is, the low salience of the target could result in its inability to be seen in peripheral vision when using the hand-held display. The current data are actually silent with regard to which of these hypotheses might be true, since detection times for the HMD was approximately 5 seconds slower for the hand-held display for both the more salient soldier (Figure 3.1.1b) and the less salient land mine (Figure 3.2.1b). Thus, it is possible that both factors were operating, and that their net effects offset each other.

The results for target detection revealed no main effect of the wall on which the target was presented, although the significant target type by wall interaction reveals substantial cost to detecting the uncued mine on the left wall. Yeh, Wickens, and Seagull (1998) found that in searching for the target, subjects moved their head clockwise, similar to the pattern used in reading text from left to right. Subjects may have turned their head from the center wall, where the head was positioned at the start of each trial, to the right immediately after the trial began. If the target was not found on the right wall, subjects then moved their head back to the center and searched that wall for objects before examining the left wall. Due to the low salience of the uncued mine, it was relatively difficult to detect; consequently, subjects may have needed to examine the right and center walls more closely (i.e., for a longer amount of time) before turning their heads to examine the left wall, thereby increasing the detection time. On the other hand, when cueing is present, habit no longer directs search; rather, the subject follows the cue to a specific area of the display and detects the target; this could explain the absence of a wall effect for the cued targets (tanks and cued mines).

The results of the target identification task (Figure 3.4.1) reflect the negative effects of clutter resulting from superimposing information on the forward field of view and warn of the potential to obscure critical information. As Figure 3.4.1 shows, the presence of the lock-on reticle superimposed over the target imposed a cost on accuracy in identifying the target (tank) as friend or foe in the head-up condition relative to the head-down condition. Further evidence to support this hypothesis is that this difference in accuracy between HMD and HHD was not present for the uncued target (the soldier), i.e., the case in which no reticle was present in the HMD condition. Thus, superimposing the reticle over the tank increased the difficulty of determining which way the barrel of the tank was pointing, the critical feature for the identification task.

In contrast to the benefit of hand-held display for target identification, its use imposed a noteworthy cost to reporting the target's azimuth. In the current experiment, although some amount of visual scanning was required by subjects when using either the HMD or hand-held display, the cost (distance) of head-down scanning to the hand-held display was greater than the cost of upward scanning to the HMD horizon line since the horizon line would sometimes be present in the field of view simultaneously with the target. Additionally, since the hand-held display was closer to the subject than the far domain, visual accommodation was necessary to bring the heading information into focus. On the other hand, information viewed through the HMD was presented at the same distance as objects in the far domain.

Thus, the combined results from the detection times and target identification and heading tasks show both a cost for clutter (which predicts the HMD cost on the low salience uncued mines and the identification accuracy disadvantage for the cued targets) and a cost for restricted field of view (which predicts the greatest cost on the detection of the more peripherally visible soldiers) on the presentation of information head-up. For the HMD, the reduced scanning when integrating information between the near and far domains facilitated subjects' ability to provide heading information but severely hindered the detection of the unexpected, high priority, nuclear devices.

The findings from the secondary task showed no difference in the accuracy of performance due to display but a difference attributable to target cueing, such that subjects detected events on the frequency jamming task more often when the target they were searching for was not cued than when it was. Note that the nature of these results are similar to those discussed earlier for the detection of nuclear devices; that is, in both cases, the presence of cueing imposed a cost on performing a concurrent task. The results for the secondary task suggest that attention was allocated in a task dependent rather than a display dependent fashion. Thus, the presentation of cueing pulled attention allocated to search, and away from the secondary task, and it made no difference whether the intensified search domain was near the cueing reticle (as with the HMD) or far away (as with the hand-held display). In either case, the added emphasis to the search task, induced by the cueing reticle, appeared to divert attention from the secondary task.

Finally, the results for the global post-task recognition task showed that subjects' mental representations of the location of objects in the environment was aided when they used the HMD rather than the hand-held display. The results of Yeh, Wickens, and Seagull (1998) revealed no difference in performance for this task between the HMD with world-referenced and screen-referenced imagery, suggesting that one's mental representation is formed not on the basis of display manipulations of symbology but may be dependent on how the environment is viewed. In the current study, accuracy on this task was poor with both displays; subjects were correct 50% of the time when using the HMD condition and 30% with the hand-held display, whereas chance performance was 25%. The results reveal the problems in using long term memory to recall what subjects may have considered incidental information, as found by Wickens, Liang, Prevett, and Olmos (1996).

Our results are thus inconsistent with previous research, which shows that a reduced field of view impairs one's ability to form a coherent representation of the world, since context, necessary for accurate recognition, is lost (National Research Council, 1997). One tentative

hypothesis which we set forth that may account for our findings is based on the idea of information overload, in the sense that one can only use a limited number of cues to develop an picture of the system or world, a heuristic commonly applied in decision making (Wickens, 1992). In the global positioning task, what was important was not how many different views of the terrain one possessed but rather knowledge of target location. Since subjects achieved the same level of performance for target detection using both the HMD and hand-held displays, it is reasonable to conclude that all subjects managed to attend to the areas of the display containing the most relevant information with respect to the global positioning task (i.e., the target's position in the environment). Thus, even though the HMD limited the amount of information available and the weight reduced the amount of scanning of the environment, subjects still attended to the "important" areas of the display. It is possible that reducing the amount of total information allowed subjects to better piece together the relevant information and thus create a more accurate mental representation of the world. On the other hand, when subjects scanned the environment freely as with the hand-held display, they acquired too much information about the terrain from moving their heads freely back and forth and as a consequence, were unable to effectively process all the pieces. These unexpected findings need to be examined further.

5. CONCLUSION

The current results replicate earlier findings of the cost-benefit trade-off of cueing (Yeh, Wickens, & Seagull, 1998). That is, a clear benefit for targets which were cued, but an important cost to *missing* high priority uncued targets in the same scene.

Importantly, these results also reveal that the cost-benefit trade-off can be modified or modulated by the platform on which cueing is presented. The use of a hand-held display slightly reduces the benefits of cueing but greatly reduced the cost of cueing to the detection of concurrent uncued high priority targets. This large benefit to the hand-held display (reducing the cost of unexpected target detection) was partially offset by a smaller cost in reporting the azimuth of targets, a cost attributed to scanning, and in recalling target locations. Thus, an absolute assessment of the "better" of the two display formats evaluated here cannot be made without considering the weights on the relative importance of the different tasks, either supported or disrupted by the display format.

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